Enhancing the Learning Effects of Dynamic Decision Game on Systems Thinking–An Experimental Study

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ABSTRACT

This study attempts to examine the effectiveness of our proposed learning environment for systems thinking, and the effects of different kinds of task's screen design for the interactive dynamic decision game to enhancing the learning effect. Two experiments were implemented for the two investigation purposes. In the first experiment, we found that the proposed learning environment was viable for learning resulting from the positive effects of challenging goal setting and causal feedback on the increase of participants' motivation and understanding of the game. In the second experiment, the effects of causal feedback was examined directly by the comparisons of three different kinds of task's screen design including causal, hierarchical, and departmental types. We found causal type of screen design induced more analytical cognitive type just as the prediction of the inducement principle (Hammond, 1988) and outperformed the other two screen design as predicted by the correspondence-accuracy principle (Hammond, 1988). But the effect of causal type on performance improvement was not significant. The insignificant effect of causal relations task's screen design on performance improvement revealed that the learning of systems thinking relied mainly on "by doing" or "by failure", not on "by knowing". In conclusion, we suggested that the design of dynamic decision game aided systems thinking learning environment should take the motivation factor into account to lead participants make more efforts to learn systems thinking by doing through failures. Although causal relations type could not improve learning effect significantly, however, it induced corresponding causal analytical cognitive type that is beneficial to the learning of systems thinking.

INTRODUCTION

Decision-makings are common in everyday life. Nobody knows what will be the results of decisions before time is up. Not only because it is hard to predict precisely under such complex and dynamic decision environment, but also because the rationality of human beings is bounded to acquire perfect information to make unbiased judgments and optimal decisions (Simon, 1957). For the purposes of enhancing decision-makers' rationality, system dynamicists have exerted themselves to the design of learning laboratory for systems thinking combined with the aid of the dynamic decision game such as People Express (PE) Management Flight Simulator (Sterman, 1988a) to cultivate the ability of business managers in handling complex system (e.g., Senge, 1989, 1990; Graham and Senge, 1990). How to design an effective learning laboratory has become an important issue for system dynamicists. The purpose of this study attempts to examine the effectiveness of our proposed learning environment for systems thinking, and the effects of different kinds of task's screen design for the interactive dynamic decision game to enhance the learning effect. Two experiments were designed for these two purposes.

The proposed learning environment we designed is based on the goal setting theory (Locke and Latham, 1990) and related cognitive theory in Social Judgment Theory (Hammond, et al., 1975). The common results of empirical studies of the goal setting effects indicate that if there is commitment to the challenging goals, adequate feedback, high self-efficacy (and ability), and suitable task strategies, high performance will be expected (Latham and Locke, 1991; Locke and Latham, 1990) . Empirical evidences from the studies in Social Judgment Theory indicate that effectiveness of the provision of cognitive feedback is superior than that of the provision of outcome feedback on multiple-cue probability learning tasks (Hammond, et al., 1973). Therefore, we tried to manipulate high challenge in the form of specific goal and provide participants causal relations feedback in the proposed learning environment in order to enhance the learning effect of systems thinking in the first experiment. For the purpose of examining the pure effects of the provision of causal relations feedback, we implemented the second experiment to compare the effects of different kinds of task's screen design, including causal, hierarchical, and departmental for dynamic decision game.

With respect to the issues in designing interactive dynamic decision games, Anderson, et al. (1990) suggested a number of general considerations including the definition of the game's purpose, the assumptions and approaches taken toward user psychology and gaming technique. On the issues of user psychology, Anderson, et al. (1990) also suggested the comparison of two kinds of gaming screens, i.e., designed from lens model perspective (Brunswick, 1956) and system dynamics, as an important topic for future research. Unfortunately, there still lacks of empirical works to examine the effects of different kinds of task's screen design. To do this, we comply with Anderson, et al.'s suggestions that the designed screens for comparison must base on cognitive theory. In 1988, Hammond proposed a theory of task systems from the cognitive point of view. There are two major principles for the predictions of decision-maker's cognitive modes. The first is the inducement principle which means that the task systems induce, but not compel, the subject to employ a form of cognition compatible with the system. The second, the correspondence-accuracy principle, when cognitive activity is found to correspond to task properties, judgmental accuracy will be greater than cognitive activity that dose not correspond to task conditions (Hammond, 1988). Based on the inducement principle, causal type of cues representation, which shows subjects causal relations among cues, will induce causal loop analysis which belong to more analytical cognitive type. In addition, causal feedback dynamic decision tasks call for causal analysis and detail computation. Therefore, it can be classified as more analytical cognitive type. Owing to the analytical characteristics of dynamic decision task, the causal type of cues representation will perform better than the other two designs based on the correspondence-accuracy principle. For measurement, Hammond (1988) proposes the cognitive continumm index to judge what kind of cognitive types (more analytical or more intuitive) used by subjects. The cognitive continumm index are calculated with six dimensions including cognitive control, rate of data processing, conscious awareness, organizing principle, errors, and confidence. On a dynamic task[1] , rate of data processing is the only suitable dimension to judge the cognitive type used by subjects. The use of more analytical cognitive type leads to slower rate of data processing.

[1] The cognitive continumm index is developed based on static tasks.

EXPERIMENT 1

In the first experiment, we manipulated challenging goal and the provision of causal relations feedback in the proposed learning environment to examine the manipulation effects on the enhancement of the learning of systems thinking.

Method

Subjects and Task

Subjects were the 86 MBA students (from two classes) at National Sun Yat-Sen University attending courses in Decision Analysis and Management Information System. All subjects were divided into two groups by class. We use People Express Management Flight Simulator developed by Sterman (1988a) to serve as decision task.

Procedure

The experiment was a two days session (three hours each day). In the first day three steps were taken: to introduce what the decision task was, how to operate the dynamic decision game and then subjects were led to play the People Express Management Flight Simulator. Subjects were asked to play the game after class. A week later, subjects joined another three-hour sub-session which included four steps. First, subjects were asked to finish the first questionnaire to evaluate the achievement of systems thinking that learned from the game playing. Second, experimenter led subjects to present their understanding about the underlying structure of the task with the tool of causal diagram. Experimenter then explained the correct structure of the task after the discussion to finish the program.

Design

For the purpose of finding a better procedure for the learning of systems thinking, the second group was asked to finish an assignment as manipulation. To finish the assignment, the participants were asked to achieve Don Burr's[2] dramatic growth as challenging goal to increase their motivation. When subjects attained the goal, they might lead the company go through quick growth and dramatic decline as the actual case of PE. Under such circumstances, subjects must try their best to rescue the company, thus they could learn something from the experience of failure or success. Besides, subjects in the second group acquired a causal diagram of the task after the first day session. As a result, this manipulation contained the effects of goal setting and causal feedback.

Subjects' performance was measured by stock price. It is from the financial management point of view that maximizing stock price is the major goal of CEOs. The other dependent variables included the number of game trials, the use of high ticket price strategy, and the achievement of systems thinking. Whether subjects used high ticket price strategy was analyzed from the collected data of the questionnaire. Achievement of systems thinking was measured by the collected data of questionnaire with the recognition of delay (Bakken, 1989) and three other indicators which were designed based on Sterman's work (Sterman, 1988b) as measures.

[2] Don Burr was the founder of the People's Express Airlines who led the company with a record high growth rate of 100% per year for several years (see Sterman, 1988b).

Results

As presented in Table 1, the number of game trials, the use of high ticket price strategy, the achievement of systems thinking, and the performance of the first group were significantly worse than that of the second group who accepted assignment manipulation. These results showed that the effect of the assignment treatment including goal setting and causal relation feedback was highly significant to motivate subjects to play more trials and stimulated them to realize the underlying structure of the system and thus to improve their performance.

Table 1. The comparison between the first and the second groups

	Dependent	Variables		
	Performance	Systems Thinking	Price-Strategy	No. of trials
	mean (SD)	mean (SD)	mean (SD)	mean (SD)
Group 1[a]	96.7(147.0)	1.0(1.0)	.13(0.34)	5.7(2.4)
Group 2	383.3(270.5)	1.9(0.9)	.66(0.48)	51.1(53.7)
F Value	16.65**	8.20*	15.44**	11.29*

[a] group 1 is the contrast group; group 2 is the manipulation group
* $p<0.01$; ** $p<0.001$

Further tests focused on the effects of moderators of performance including the number of game trials, the use of high ticket price strategy, and the achievement of systems thinking. As shown in Table 2, there existed significant positive relations between performance and the number of trials, the use of high ticket price rule , and the achievement of systems thinking ($F(3,34)=42.36$, $p<0.0001$; $F(3,34)=18.03$, $p<0.0002$; $F(3,34)=5.86$, $p<0.003$, respectively). The multiple R square was 0.77. The results showed that performance was affected by the number of game trials, the use of high ticket price strategy, and the achievement of systems thinking. The use of high ticket price strategy was the most significant factor.

Table 2. Performance and its affecting factors

	No. of Trials[a]	Price Strategy	Systems Thinking
level 1	78.07	142.88[b]	123.67
level 2	318.00	438.26	243.21
level 3	335.79		378.15
level 4	570.11		401.27

[a] the number of trials is divided with quartiles into four levels
[b] level 1 represents the use of high ticket price strategy

We then tested the effects of the number of game trials on the achievement of systems thinking and the use of high ticket price strategy. As presented in Table 3, the relationship between number of game trials and systems thinking was positively significant, and so was price strategy. The results suggested that, the more the subjects played the game, the more they might understand the underlying structure of the system and found the price strategy to use.

Table 3. The effects of the number of game trials on systems thinking and the use of high ticket price strategy

	Dependent Variables	
number of trial	Systems Thinking	Price Strategy
	mean (SD)	mean (SD)
level 1	1.09(1.22)	0.13(0.35)
level 2	1.50(1.07)	0.50(0.53)
level 3	1.93(0.73)	0.71(0.47)
level 4	2.22(0.83)	0.67(0.50)
F Value	F(3,41)=2.71	F(3,45)=4.71
Prob.>F	0.0583	0.0064

Those results described above showed the effects of our proposed learning environment. The challenging goal setting motivated participants to play the game more times. As participants played the game more times under the aid of causal relations feedback, they could realize the underlying operation rule of the system through the learning from failure. Consequently, by learning the systems thinking skill subjects might find the high ticket price strategy to improve performance.

EXPERIMENT 2

In the second experiment, we designed three types of task's screen, including causal, hierarchical, and departmental types, to examine the pure effects of the provision of causal relations feedback on the enhancement of the learning of systems thinking.

Method

Task

The decision task used in this experiment simulated a business management decision-making problem. The macrodynamic decision environment we designed from Forrester's "market growth" system dynamics model (Forrester, 1961) and implemented in Chinese on a Macintosh computer using HyperCard software. Subjects were presented information related to financial, personnel, manufacturing, and marketing departments of the simulated company for a single quarter year or historical time series data, numerically or graghically. Two decisions were made each quarter year including how many salesmen to hire and how much investment to make on manufacturing. The decision goal was to maximize total assets throughout 32 quarter years. Three principles should be complied to make correct decisions. The first principle was to match the sales volume with the manufacturing capacity. The second principle was to match the cash and expenditure to avoid bankruptcy for the shortage of cash and utilize available cash completely. The third was the consideration of delay in decisions.

Design

The experiment utilized a 2*3*3 factorial design, with one manipulation that related to the task's screen design, to examine the effects of different kinds of cues representation. The other two manipulations were not reported here. There were three kinds of task's screen design including causal, hierarchical, and departmental for the dynamic decision game.

The causal type of screen was designed like the causal diagram used by system dynamicists to represent the relations of variables. The hierarchical type of gaming screen was designed with lens model's perspective. The example shown in figure 1 represented that total assets was correlated with total cash and total value of capital, and so on. The departmental type of screen represented cues with the classification of departments of simulated company. Since the departmental type is the most common way to represent company's information, it can served as the contrast of the other two conditions.

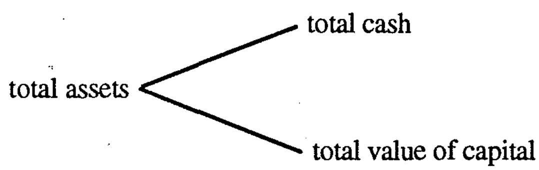

Figure 1. A demonstration example of hierarchical type of screen design

The dependent variables included (1) induced information searching behavior, measured by the number of searched information term and mean inspecting time on each searched information term, (2) subjects' mental model correctness, to measure the performance by cognitive system, and (3) decision performance, to measure the performance by decision outcomes. The number of searched information and inspecting time on each searched information term were acquired through an automatic recording system of our computer program. Subjects' mental model correctness were analyzed by the descriptions of their own decision strategies as protocol analysis inputs. Then the reported decision strategies were compared with the three principles for correct decisions to code the degree of subjects' mental model correctness. Decision performance was measured by the mean total assets and order growth rate averaged over 32 decision quarter years.

Procedure

Subjects were provided with a five-page set of written instructions with the initial conditions of the simulated company, the relationships among all variables in the task with listed equation, the reward structure, and the goal of decision task (maximize the assets). Throughout the decision process, the subjects' mental model which related to how to manage the simulated company and their decision strategies were recorded. Subjects could refer any feedback information before making each decision. Each trial consisted of 32 quarter years. Subjects were asked to finish three complete trials in addition to bankruptcies. It took subjects about 1.5 to 3 hours to finish the experiment.

Subjects

The subjects were volunteers and all were undergraduate students with the department of business management at National Sun Yat-Sen University in Taiwan. Seventy two participants were randomly assigned to the 18 cells of the factorial design.

Results

Induced Information Searching Behavior

The number of searched information term represents the range of information searching. The mean inspecting time on each searched information term represents the rate of information processing. The mean number of searched information term for causal, hierarchical, and departmental types of screen design were 269, 218, and 195 respectively ($F(2, 50)=4.07$, $p<0.03$). The mean inspecting time for causal, hierarchical, and departmental types of screen design were 1.28, 0.82, and 1.06 seconds respectively ($F(2, 50)=2.74$, $p<0.08$). The results illustrated causal type of screen design induced the information searching behavior that characterized with wider range of information searching and slower information processing rate. That is, causal type induced more analytical cognitive type compared with the departmental condition. Moreover, wider range of information searching and quicker information processing for hierarchical type indicated that hierarchical type induced more intuitive cognitive type compared with the departmental condition.

Moreover, correlational analysis showed significant relations between information processing rate and both of the performance measured by subjects' mental model and the decision outcomes. The mean correlation coefficients averaged over three trials were 0.37 ($p<0.05$) and 0.50 ($p<0.001$) respectively. The results complied with the prediction of the correspondence-accuracy principle that more analytical cognitive type, with slower information processing rate, leads to better performance on the causal feedback dynamic task which belong to the more analytical task.

Performance of Subjects' Mental Model Correctness

The subjects' mental model correctness is presented in Table 4. Table 4 revealed that the initial correctness of subjects' mental correctness for three groups were nearly the same, the result of ANOVA indicated no significant differences either. In the three finished trials, the correctness for causal type was higher than hierarchical and departmental types. Nevertheless, mean differences among three types were significant only in the first trial ($F(2,49)=2.83$, $p<0.07$). Though there was significant trial effect, the interaction effect between trial and manipulation was not significant. The results showed that there did existed learning effect, as shown in the mean raw of Table 4, but the size of the learning effect was not influenced by the screen design.

Table 4. Subjects' mental model correctness

	initial	1st	2nd	3rd
causal	0.58	0.92	1.25	1.29
hierarchical	0.58	0.54	1.04	1.25
departmental	0.33	0.54	0.92	1.00
mean	0.50	0.67	1.07	1.18

Decision Performance

As presented in Table 5, the causal type outperformed the other two conditions and hierarchical type outperformed departmental type both on total assets and order growth rate. However, the results above were not statistically significant.

With respect to the learning effect, decision performance on total assets and order growth rate were improved from trial to trial as shown in the mean column of Table 5. The trial effect tested by MANOVA were significant both on total assets and order growth rate (Wilks' Lambda=0.79, $F(2,48)=6.21$, $p<0.005$; Wilks' Lambda=0.73, $F(2,48)=8.71$, $p<0.002$). However, there was no significant interaction effect between

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trial and manipulation. The results demonstrated that there did exist learning effect, as shown in the mean column of Table 5, but the size of the learning effect was not influenced by the screen design.

With respect to the correlation between two types of performance measures, the results of correlation analysis supported the positive relation between understanding and decision outcomes. The mean correlation coefficient between mental correctness (i.e., understanding) and total assets was 0.57 ($p<0.001$), mental correctness and order growth rate was 0.54 ($p<0.001$). The results supported the consistency between two types of performance measured by cognitive system and decision outcomes.

Table 5. Decision performance

		causal	hierarchical	departmental	mean
total assets	1st	2.69E+05	4.04E+04	3.67E+05	2.25E+05
	2nd	3.97E+08	2.08E+06	7.94E+05	1.33E+08
	3rd	7.87E+10	1.51E+07	2.56E+06	2.62E+10
	mean	2.64E+10	5.74E+06	1.24E+06	8.78E+09
order growth rate	1st	0.31	0.25	0.24	0.27
	2nd	0.43	0.35	0.34	0.37
	3rd	0.49	0.46	0.36	0.44
	mean	0.41	0.35	0.31	0.36

DISCUSSION AND CONCLUSION

In the first experiment, we found that the proposed learning environment was viable for learning resulting from the positive effects of challenging goal setting and causal feedback. The challenging goal motivated participants to play the game more times. As participants played the game more times, under the aid of causal relations feedback, they could realize the underlying operation rule of the system through the learning from failure. Consequently, subjects learned the systems thinking skill might discover the high ticket price strategy to improve performance.

Furthermore, the findings of the present study supported the positive relationship between understanding (measured by systems thinking in the first experiment and by mental model correctness in the second experiment) and performance argued by Bakken (1989). However, the use of high ticket price strategy was the most significant affecting factor of performance suggested that the positive relationship might be interfered with the use of price strategy under the condition when the strategy was just acquired by try and error but not by understanding. That is, understanding may just be a necessary condition for high performance.

In the second experiment, the effects of causal feedback was examined directly by the comparison of three different kinds of task's screen design including causal, hierarchical, and departmental types. We found causal type of screen design induced the information searching behavior that characterized with wider range of information searching and slower information processing rate. That is, causal type of task's screen design induced more analytical cognitive type as the prediction of inducement principle. Referring to the prediction of correspondence-accuracy principle, the causal type indeed outperformed the other two screen design although was not statistically significant. The results also arised an interesting question: why the provision of a clear underlying causal structure of the task could not lead to "significant" improvement of performance?

We think there might be four probable causes of this learning disability. First of all, subjects ignored the importance of delay. We found that information delay was evaluated as the least important considerations by subjects in post-experiment questionnaire. Secondly, subjects failed to recognize the gap between expected goal and actual state. We found that about 90 percents of the bankruptcies occurred within 10 quarter years resulting from the ignorance of initial conditions. The initial total cash of the simulated company could not support too much growth. Thirdly, subjects were subject to using functional relation seeking strategy but not pattern seeking strategy. For example, they often sought for the functional relation between order growth rate and the number of hired salesman, yet ignored the other affecting factors, e.g., reputation of the company. Fourthly, subjects preferred to find a static decision rule such as the optimal ratio between hiring and investment. However, static rule was hardly ever the optimal one on dynamic decision tasks. Unfortunately, although the provision of causal relations let subjects know what was the relations among variables, it was useless for the avoidance of the four causes of this learning disability. That is, subjects could learn systems thinking adaptively mainly "by doing" or "by failure", not "by knowing".

In conclusion, we suggest that the design of a learning environment with the tool of dynamic decision game should take the motivation factor into account, such as, to set challenging goals, to lead participants put more efforts to learn systems thinking by doing. Although causal relations type of task's screen design can not improve learning effect significantly, however, it can induce corresponding analytical cognitive type to increase the cognitive efforts on the inspection of information that is beneficial to the learning of systems thinking.

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